AIR-OIL SEALS R&D AT ALLIEDSIGNAL

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Dr. Rifat Ullah from AlliedSignal will be talking about air-oil seals research and development at AlliedSignal.

I've noticed that we are the only people in this gathering today working on air-oil seals R&D. At AlliedSignal we're looking at several seal types though the major emphasis these days is on air-oil seals that affects our engines business today.

Now, let me define what I mean by air-oil seals. Here is a schematic of a generic air-oil seal; the numbers are just illustrative; of course, they vary. The air-oil seals we have at AlliedSignal, most have high pressure air on the ID side of the carbon, and a mixture of oil+air in some form on the OD side of the carbon; we call such an arrangement a "buffered seal". The oil side of the seal is typically the bearing compartment. And we have air leakage from the air side and oil leakage from the oil side, this latter leakage is very undesirable. So, the problem is to keep the oil on the oil side with 100% reliability with minimal air leakage. In this schematic of a typical face seal from a propulsion engine, some of the key parameters are: 85 psia air at 550F, 400F oil-air at around ambient conditions, with the rotor at 30,000 rpm, and so forth. The oil side in many cases are splashed oil from the bearing, while in other cases cooling is aided with oil jets, or our proprietary film cooling scheme. Now, many of our problems we experience involve carbon face seals, more than, for example, ring seals.

Now, why are we working so feverishly on air-oil seals at this point in time? Air-oil seals have become big maintenance drivers for AlliedSignal, since reliability of other components (turbines, compressors, combustors, etc.) have gone up significantly in recent years. The biggest customer complaint is odor in cabin (or OIC). For example, when an APU compressor seals leak, it can send odorous air into the cabin, and with more push towards no-smoking flights these days the OIC problem becomes more perceptible, heightening customer complaints. With AlliedSignal being the largest commercial APU manufacturer in the world, the pressure to correct such problems is acute. Other complaints are high oil consumption, oil leaks into vents, oil on the ground. And, of course, this leads to premature engine removal and increase in maintenance and warranty costs. So, that pretty much motivates our efforts at this point in AlliedSignal history.

OK, what are some of the major failure modes going on? Here are some: The oil leaks into the air side due to the presence of coke. We've tried to scrub our engine reliability data for some time now; and as you may know, reliability data is not always clean; for example, seals sometimes are secondary causes but can get cited as primary cause of engine removal. However, some causes are quite clear. For example coking. Other causes include, oil leaks due to carbon blistering and wear; oil leaks without the presence of coke, etc. These then are the areas we're either working on, or are planning to work in the near term.

Here's a snapshot of our 'current' activities and the rest of my presentation is going to be briefly touching on as many of these programs as I can.

First, FACE SEAL TRACKING DYNAMICS PREDICTION TOOL. The aim is to predict the minimum face load needed for tracking. Any lower load and the seal would not track, and with higher unnecessary loads the seal generates a lot of heat causing coking. So, we did experimental validation of some available correlations, essentially comparing Hart&Zorowski with Green&Bair. We found that Hart&Zorowski was more conservative for our seals, so we are adopting that.

Next, OIL COKING. Through an experimental program, we have gained a fundamental understanding of how oil converts into coke. We've developed certain tests to measure coking. We've produced guidelines on seal design to avoid coking with time-temperature relationships. We've determined the effects of various common oil types, and very importantly, we've identified materials that resist or accelerate coking. We've discovered the fundamental mechanism by which oil converts to coke. This figure here shows the different regimes of the coke formation process. The antioxidant in the oil comes down as a precipitate under certain conditions. The x-axis is timed in minutes and the y-axis for this curve is the amount of antioxidant remaining in the oil. As soon as the antioxidant depletes, there some intermediate molecules (polymers) that begin to form. They are small enough to be soluble in oil, so they do not fall out. But after some time in such distressed state (time at temperature), the intermediate molecules form larger chains and drop out as coke and other deposits. So, if one can somehow continue to dissolve the intermediate polymers and carry them away from stagnant surfaces, that is one of several important conclusions from this work. The goal should also be to minimize the dropping of the antioxidant levels so that intermediate polymers do not form. Now, the effect of the oil type used. What this shows is the time for the antioxidant to deplete to 10% level, for several common oil types. As you can see, differences of orders of magnitude is evident. So, picking the right brand of oil can help combat the coking problem in aerospace engines. What we are trying to do is to educate our customers, among other things. The effect of solid materials that come in contact with oil is highly eye-opening, and we cannot talk about that here, since intellectual property rights have not yet been secured.

Next, TRIBOPAIR FRICTION DATA FOR SEAL DESIGN. We've determined friction coefficients for 10 common tribopairs. Realistic operating conditions were simulated when possible, and realistic geometries were used, as opposed to pin-on-disk. We measured friction coefficients, wear rates, seal temperatures, etc. Three of the best couples were identified. The general idea is to use such data in analytical models for seal designs.

Next, FACE SEAL MODELING/ANALYSIS TOOLS for practical use. Practical design/analysis tools are being developed in cooperation with MSTI (Dr. Alan Lebeck, principal). These tools predict the seal temperatures, deformations, stresses, air leakage, etc. The practical tool integrates a finite element code with solution of the Reynolds equation in an interactive fashion. Further efforts includes experimental validation of the tools. A validation test rig, with slip rings, has been developed at AlliedSignal.

Next, ACTIVE COOLING OF SEALS WITH OIL. To obtain engineering data AlliedSignal is performing experimental heat transfer work with Arizona State Univ. These data will be used in modeling codes for seal design & analysis. The experimental work uses lumped capacitance method to measure heat transfer coefficients for several different cooling schemes: (a) Oil Jets, which is a conventional method; (b) Oil Film, which is an AlliedSignal patented technology; and some other innovative schemes. We have studied the oil jetting in some details, while oil film cooling rig is begin built currently, which will also study other innovative schemes.

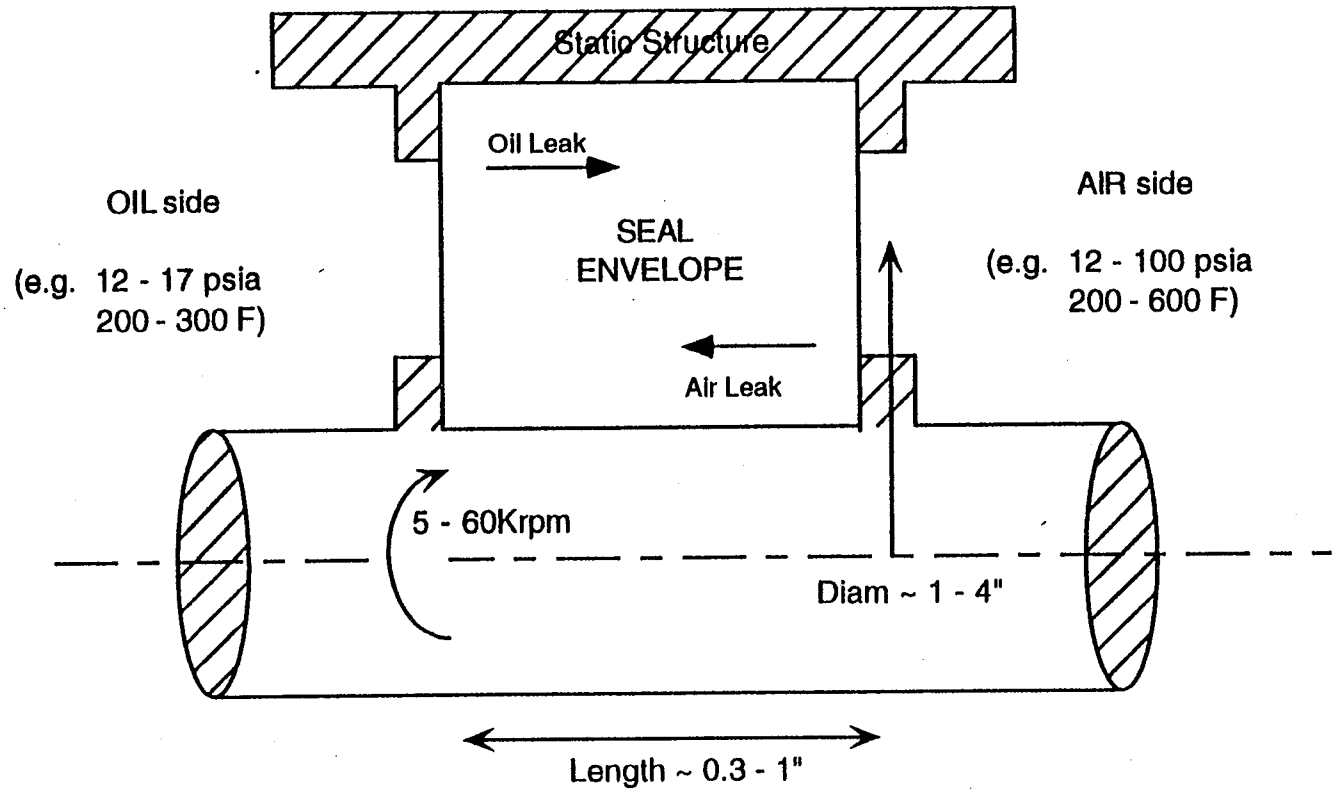
Next, CERAMIC AIR-OIL SEALING DEVICE INVENTED. AlliedSignal has recently invented and developed the first air-oil seal for the mainshaft of jet engines that uses ceramics, in order to withstand tough sealing service conditions. The patented device is a segmented ring seal where the runner (or rotor) is made of ceramic. The performance of this device has been highly successful in the first application --- TFE731 turbofan engine. The ceramic seal has been thoroughly tested in the lab and is currently being field tested. This innovative seal solves a chronic sealing problem that was being experienced by a number of sealing locations of this popular turbofan engine. This seal can be used in many other air-oil sealing situations in gas turbine engines.

FUTURE R&D will continue to focus on other air-oil seal reliability drivers. Plans for 1997 include: (a) Carbon seal blister prevention; (b) Development of seal design data; (c) Hydropad seals for jet engine applications; (d) Practical innovative air-oil seals with the goal of zero oil leakage; etc.

As we continue to work aggressively on solving air-oil seal problems for gas turbine engines, we continue to look for "strategic partnerships" with entities outside AlliedSignal. Thank you.

SCHEMATIC OF A GENERIC AIR/OIL SEAL

(The numbers are only illustrative and they vary)

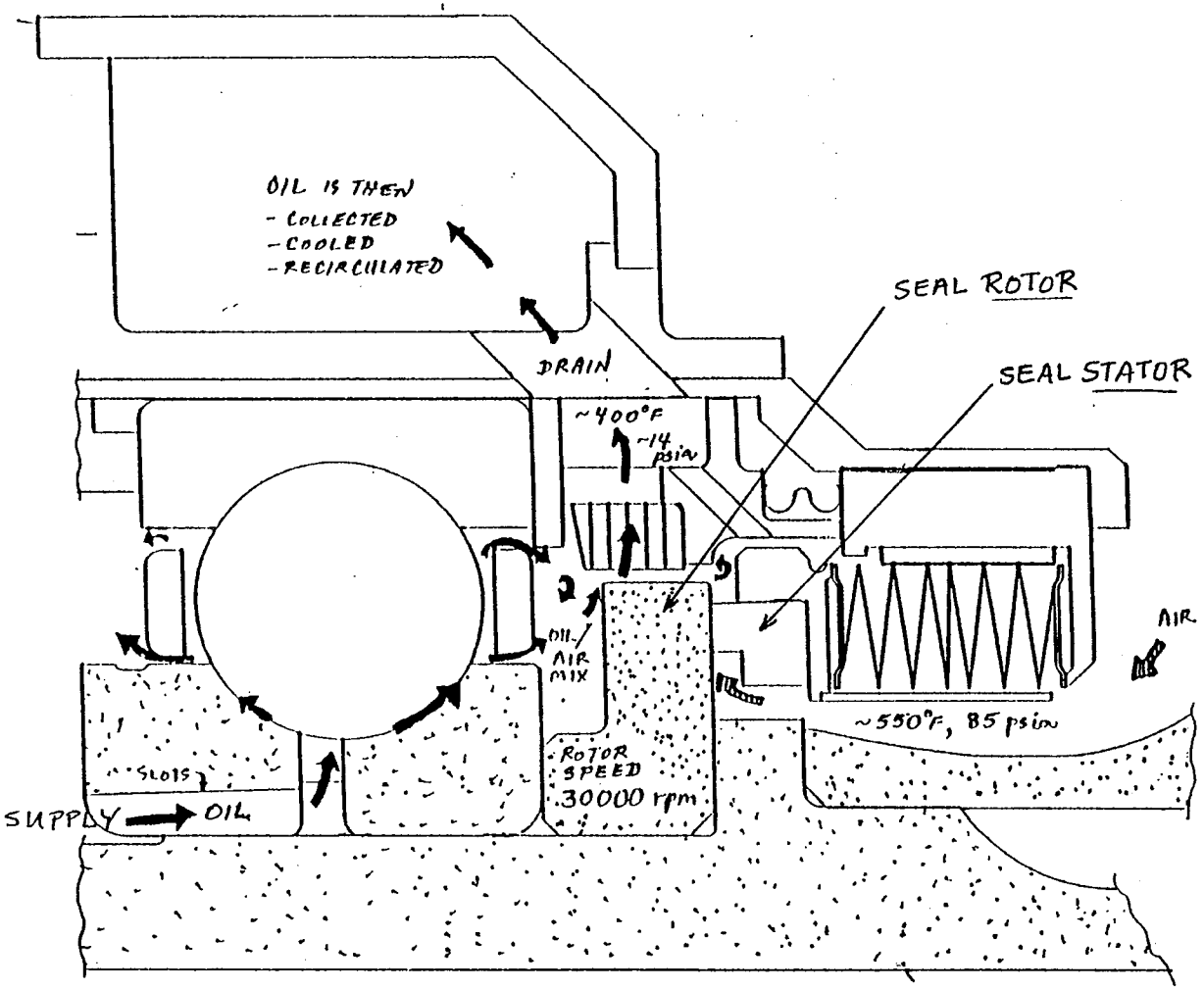


PROBLEM: <u>Keep Oil on Oil-side with 100% Reliability</u>
(with minimal Air leakage)

Proprietary

AlliedSignal
AEROSPACE

Schematic of a Mechanical Face Seal



PROPRIETARY
ALLIEDSIGNAL

AlliedSignal is Committed to Improving Air/Oil Seals Reliability

- Air/Oil Seals have become Maintenance Drivers
- Biggest Customer Complaint is "Odor In Cabin"
- Other Complaints: High Oil Consumption, Oil Leaks to Overboard Vents, Oil on Ground, etc.
- Premature Engine & Seal Removals
- Increased Maintenance and Warranty Costs

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Common Failure Modes have been Identified

- Oil Leaks into Air-Side of Seal due to presence of Coke
  - » Seal runs hot causing oil to coke
  - » Coke prys open sealing interface
- Oil Leaks due to Carbon Wear and Blistering
- Oil Leaks without the presence of Coke

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AlliedSignal AEROSPACE

AlliedSignal is in Forefront of Air/Oil Seals R&D

- Current activities:
  - » Seal Tracking Dynamics Analytical Tool Development
  - » Coking Chemistry: Mechanisms & Design Guidelines
  - » Tribopairs Friction Coefficients under Realistic Conditions
  - » Face Seal Comprehensive Analytical Tools Development
  - » Oil Cooling Heat Transfer Research & Design Data
  - » Ceramic Seals Innovation

- Future activities are Planned

Seal Tracking Dynamics Modeling & Analysis Tools Developed

- Design/Analysis Tool Development. Predict: Minimum Face Loads Requiment for *Bellows Carbon Face Seals*
  - » Contacting faces (i.e. No Fluid Film effects)
  - » Pressure balanced (i.e. No significant Pressure effects)

- Experimental Validation of the Design/Analysis Tool, with Rig developed at AlliedSignal

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Oil Coking Chemistry & Design Guidelines Developed

- Produced Fundamental Understanding of How Oil Converts to Coke
- Tests developed to Measure Coking
- Guidelines for Seal Design include:
  - » Coking Time-Temperature relationships
  - » Effect of Oil Types
  - » Effect of Materials (Catalysis)
- Potential Oil Testing Procedure Identified which could provide Early Warnings of Coking

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Tribopairs Friction Design Data Developed

- Determined Friction Coefficients for Tribopairs -- 10 couples were studied
- Realistic Operating Conditions and Geometries
- Measured: Friction coefficient, Wear rates, seal Temperatures, etc.
- Three best couples were identified

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AlliedSignal AEROSPACE

Face Seal Modeling & Analysis Tools Developed for Practical Use

- Practical Design/Analysis Tools Predict: Temperatures, Deformations, Stresses, Air-Leakage. MSTI (Lebeck) codes.

- Includes Experimental Validation of the Design/Analysis Tools

- Validation Test Rig developed at AlliedSignal

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Oil Cooling Heat Transfer Research, Design Data Developed

- Experimental Convective Heat Transfer
- Overall Heat Transfer Coefficients using Transient Lumped Capacitance Method
- To Be Used in Seal Models & Analyses
- Current effort includes:
  - » Oil Jets (conventional method)
  - » Oil Film Cooling (AlliedSignal proprietary, patent pending)
  - » Other Innovations are being Investigated

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Ceramic Air/Oil Sealing Device Developed

- AlliedSignal Patent pending Technology is a Robust Solution to addressing Tough Air/oil Sealing situations for Mainshaft Seals

- First ever Insertion of Ceramics in Mainshaft of Production Aircraft Gas Turbine Engine ... Unique Achievement

- Field Tests in progress

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FUTURE R&D will Focus on Air/Oil Seal Next Level Reliability Drivers

Plans for 1997 include...

- » Carbon Blistering & Wear
- » Ceramic Seal Operability Limits
- » Oil Leakage Control using proprietary schemes
- » Practical "Non-contacting" Air/Oil Seals Development
- » High Performance Oil Scavenging

Strategic Partnerships with Entities Outside AlliedSignal are Welcome!!

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